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(54) Abstract Title

Frequency selective surface filter for an antenna

(57) A frequency selective surface filter (50) particularly useful in connection with a transmit antenna (10) for passing and rejecting signals in multiple frequency bands. The frequency selective surface filter (50) contains two dielectrically separated conductive layers including a first conductive layer (52) having an array of double-slots made up of an inner slot (64) and an outer slot (66). The double-layer configuration further includes a second conductive layer (60) made up of an array of single conductive loops (62).

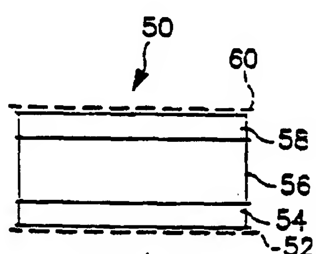

FIG. 5

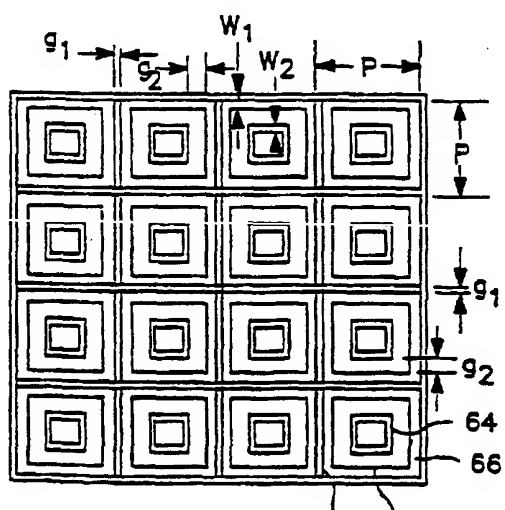

FIG. 6

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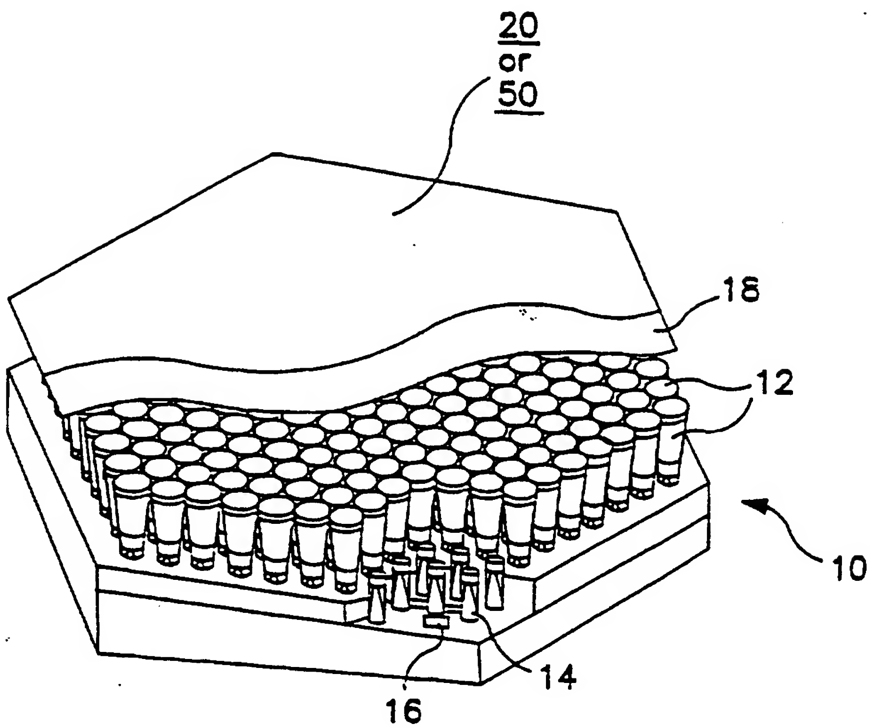

FIG. 1

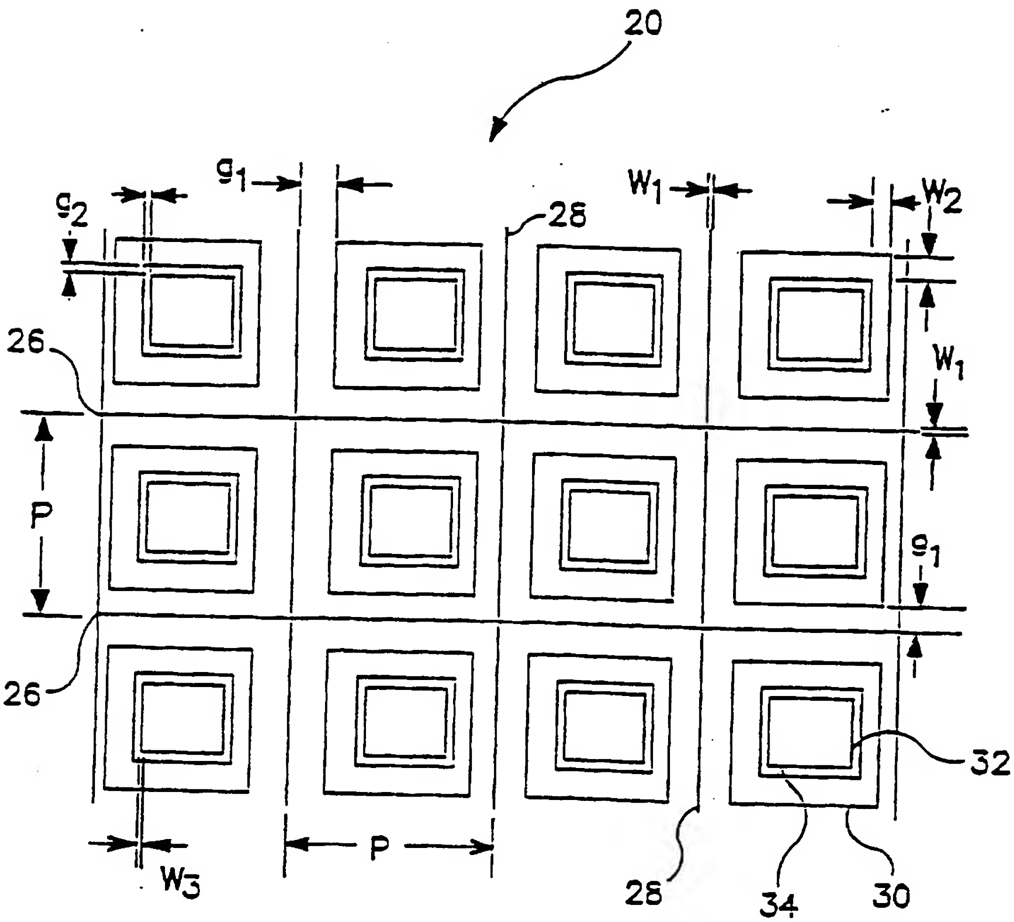

FIG. 3

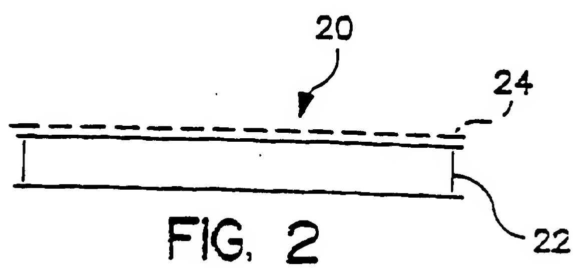

FIG. 2

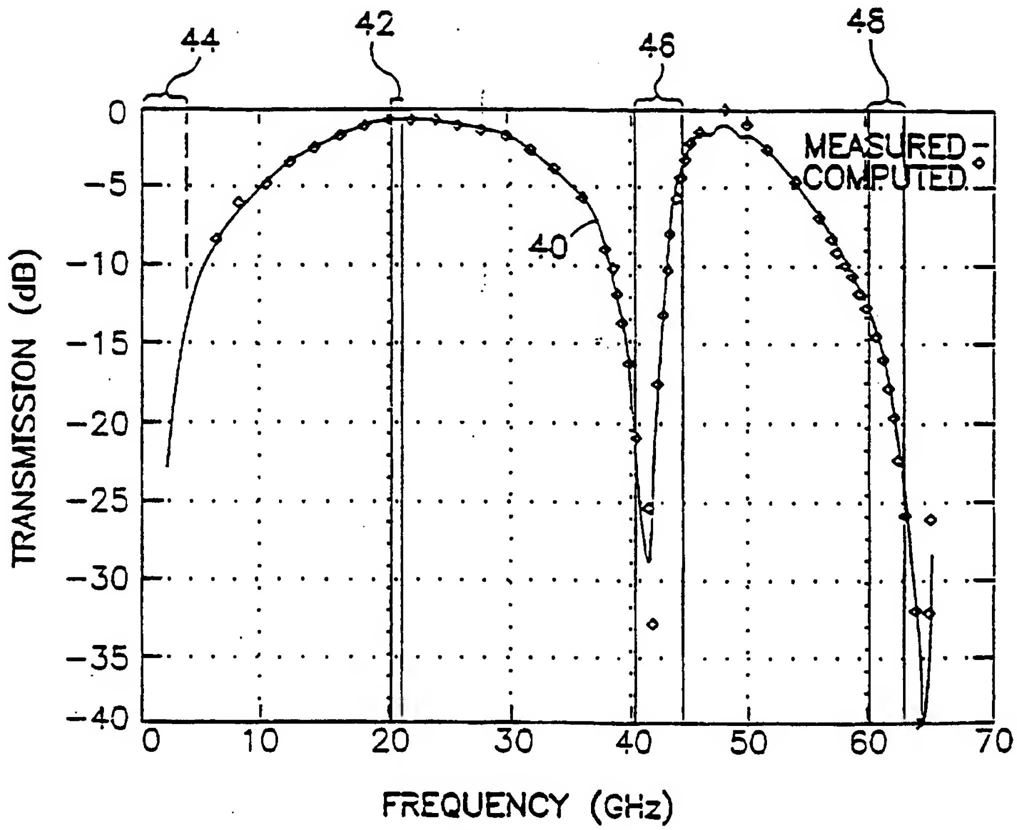
44
42
46
48
0
-5
-10
-15
-20
-25
-30
-35
-40
TRANSMISSION (dB)
MEASURED
COMPUTED
40
0
10
20
30
40
50
60
70
FREQUENCY (GHz)

FIG. 4

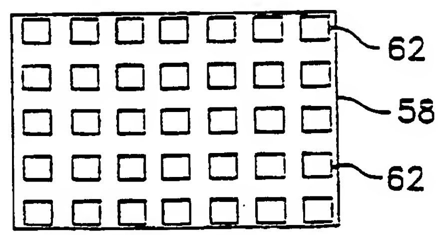

FIG. 7

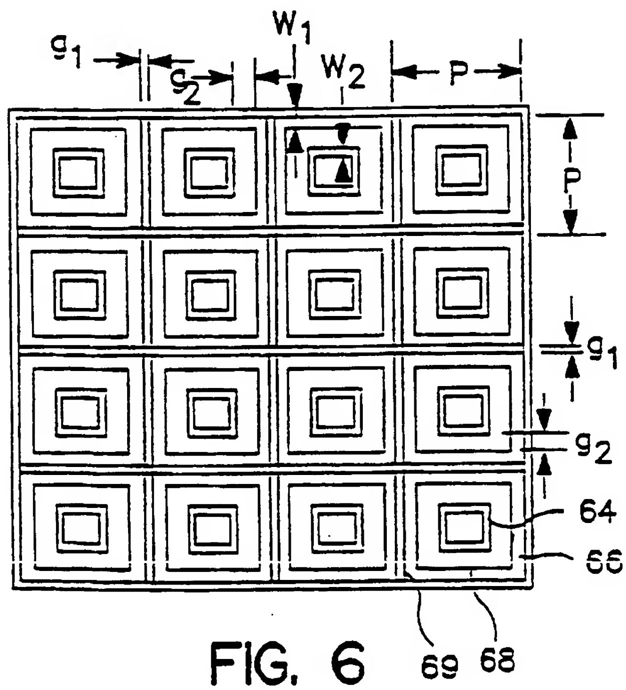

FIG. 6

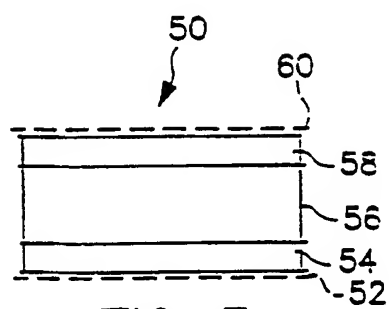

FIG. 5

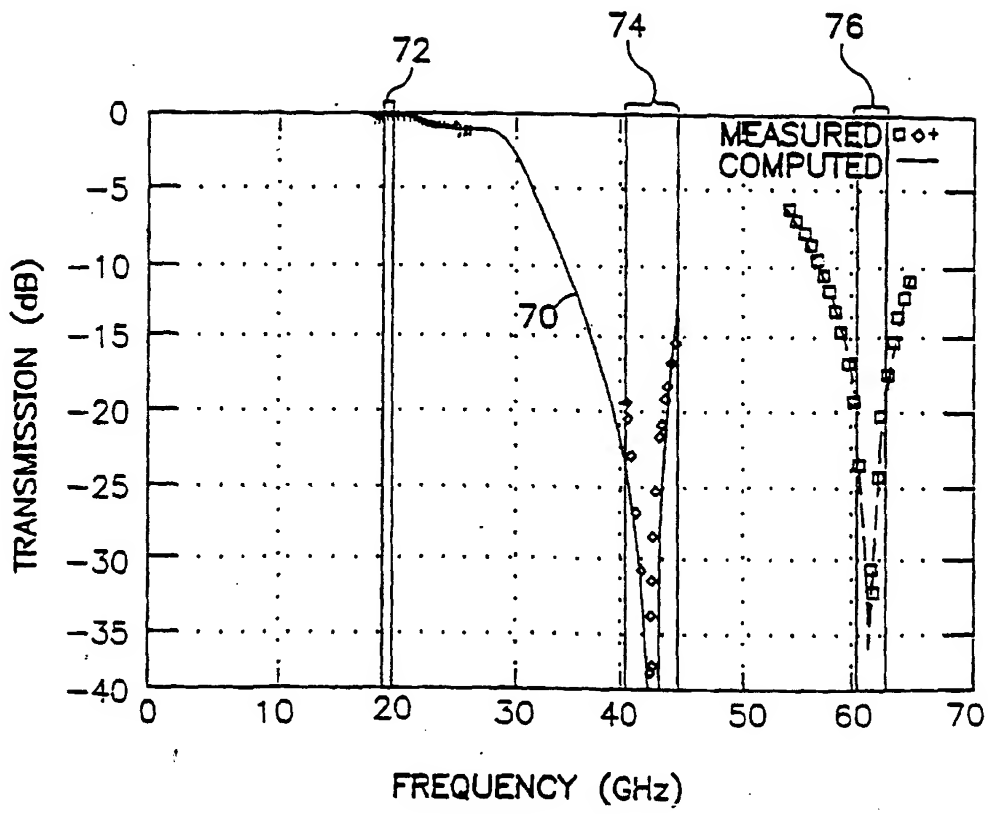
72
74
76
MEASURED
COMPUTED
70
TRANSMISSION (dB)
0
-5
-10
-15
-20
-25
-30
-35
-40
0
10
20
30
40
50
60
70
FREQUENCY (GHz)

FIG. 8

FREQUENCY SELECTIVE SURFACE FILTER FOR AN ANTENNA

BACKGROUND OF THE INVENTION

1. Technical Field:

This invention relates generally to a frequency selective surface (FSS) and, more particularly, to a frequency selective surface filter for passing and rejecting signals in multiple selected frequency bands and for use in connection with an antenna.

2. Discussion:

Frequency selective surfaces have been used in connection with wireless transmission systems such as antenna systems to reject the transmission of signals in a selected frequency band, while allowing signals in a selected frequency band to pass through the frequency selective surface. Accordingly, the frequency selective surface can advantageously be used to filter out signals at a certain frequency. Frequency selective surfaces are especially useful for satellite antenna systems where multiple signals at different frequencies may be present and only selected frequency signals are to be transmitted to or from a given antenna system device.

Known frequency selective surfaces have generally consisted of an array of conductive elements fabricated on a dielectric medium. The dielectric medium is generally transparent to signal radiation, while the conductive elements

are configured to selectively allow signals of certain frequencies to pass therethrough and reject signals at other frequencies. Typically, the conductive elements are often configured as closed loops, usually configured as square loops or circular loops. Generally speaking, the dimensions of the conductive elements determine the passband and rejection band of the frequency selective surface. The use of an array of conventional single conductive loops of identical size and shape will provide a single narrow band of rejection. However, the single loop configuration provides only limited signal rejection in a rather narrow frequency rejection band.

More recently, a double-loop frequency selective surface has been used in connection with a dual reflector antenna. One example of such a double-loop frequency selective surface is described in U.S. Patent No. 5,373,302, entitled "Double-Loop Frequency Selective Surfaces For Multi Frequency Division Multiplexing in a Dual Reflector Antenna", issued to Wu on December 13, 1994. The aforementioned issued U.S. patent is incorporated herein by reference. The double-loop frequency selective surface configuration provides an array of two different size conductive loop elements on a sub-reflector which reflect signals at two different frequency bands back into a main reflector. While dual frequency reflection bands are obtainable, each of the reflection bands effectively reflects signals over a narrow range of frequencies.

In more recent times, it has become desirable to provide signal filtering for antenna operations. The multibeam phased array antenna has been

developed especially for use on a satellite system which can be operable at various operating frequencies. For example, in a multiband communication system, a transmit antenna may be operable to transmit signals at frequencies in the K-band such as 20.2 to 21.2 GHz, while a receive antenna may be operable to receive signals at frequencies in the Q-band such as 41 GHz. Further, crosslink communication among satellites may operate at frequencies in the V-band such as 62.6 GHz. One problem that may arise with the transmit antenna is that the antenna's transmit circuitry generally employs power amplifiers which exhibit non-linear characteristics. These non-linear power amplifiers as well as other non-linear circuitry which are commonly provided in active antennas may produce high frequency second and third harmonics. The high frequency second and third harmonics generated by the transmit antenna can interfere with the receive and crosslink channels, unless adequate signal filtering is provided. Such a filtering device for spaceborne satellite systems and the like is generally required to be small and as lightweight as possible.

It is therefore desirable to provide for a frequency selective surface that provides both signal passing in a specified frequency band and signal rejection in multiple frequency rejection bands. It is also desirable to provide for such a frequency selective surface that realizes wide bandwidth frequency rejection. It is further desirable to provide for a frequency selective surface for use with an active antenna. It is particularly desirable to provide such a frequency selective surface filter for filtering out unwanted signals caused by the amplifier's

high frequency harmonics, especially with a transmit antenna. Yet, it is further desirable to provide a frequency selective surface with multiple frequency rejection bands in a compact, low cost and lightweight package suitable for use on a spaceborne or ground antenna system.

SUMMARY OF THE INVENTION

In accordance with the teachings of the present invention, a frequency selective surface filter is provided for passing and rejecting multiple frequency bands.

The frequency selective surface filter comprises a dielectric medium that is substantially transparent to electromagnetic signal transmission and having a top surface and a bottom surface;

a plurality of double-loop slots disposed in a first conductor material on one of said top and bottom surfaces of said dielectric medium, each of said double-loop slots including an inner slot encircled by an outer slot for providing a first frequency pass-band and a second frequency pass-band while rejecting signals in a first frequency rejection band; and

an array of conductive loop elements disposed on the other of said top and bottom surfaces of the dielectric layer, for providing a second frequency band.

The frequency selective surface is compact and lightweight and is particularly useful in connection with a transmit antenna such as a multibeam phased array transmit antenna. According to one application, the frequency selective surface filter is disposed in communication with the multibeam phased array transmit antenna to allow for the transmission of signals within a first designated frequency band. The frequency selective surface filter filters out signals within the rejection bands, especially those signals having frequencies associated with second and third harmonics caused by non-linear elements in the transmit antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the present invention will become apparent to those skilled in the art upon reading the following detailed description and upon reference to the drawings in which:

Figure 1 is a partial cut-out view of a multibeam phased array

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transmit antenna having a frequency selective surface filter disposed on the top surface thereof;

Figure 2 is a cross-sectional view of a single-screen frequency selective surface filter;

Figure 3 is a top view of a portion of the single-screen frequency selective surface filter of Figure 2;

Figure 4 illustrates one example of the signal transmission response that may be realized for the single-screen frequency selective surface filter;

Figure 5 is a cross-sectional view of a double-screen frequency selective surface filter having two conductive layers according to the present invention;

Figure 6 is a bottom view of a portion of the bottom layer of the double-screen frequency selective surface filter of Figure 5;

Figure 7 is a top view of a portion of the top layer of the double-screen frequency selective surface filter of Figure 5; and

Figure 8 illustrates one example of the signal transmission response that may be realized for the double-screen frequency selective surface filter.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning now to Figure 1, a multibeam phased array transmit antenna

10 is provided with a frequency selective surface filter 20 or 50 in accordance with the present invention. The multibeam phased array antenna 10 is particularly suited for use in connection with a satellite communication system which may include both transmit and receive antennas for communicating with ground based communication systems. As one example, the transmit antenna may be operable for transmitting signals having frequencies of approximately 20.2 to 21.2 GHz within the K-band, while the receive antenna may be operable to receive signals having frequencies of approximately 40.4 to 45.5 GHz within the Q-band. In addition, a satellite communication system may include antennas for transmitting and receiving cross link communication signals among various satellites at frequencies of approximately 60.6 to 63.6 GHz within the V-band. The phased array antenna 10 as shown and explained in connection with the present invention is a transmit antenna. However, it should be appreciated that the frequency selective surface filter employed in connection with the antenna 10 may be applicable for use in connection with various commercial and military antenna and radome systems for both receive and transmit antennas, and the frequency bands of operation may be scaled to other frequency bands, without departing from the principles of the present invention.

The multibeam phased array antenna 10 as shown includes an array of metalized plastic feed horns 12 configured side-by-side in a planar arrangement. However, antenna 10 may include a single radiating element or multiple radiating elements configured in various other configurations including a

curved configuration. The antenna 10 described herein is a transmit antenna for transmitting transmit signals at frequencies of 20.2 to 21.2 GHz within the K-band. The antenna 10 includes a circular-to-rectangular transition element 14 and a beam forming network with amplifiers 16. In addition, the multibeam phased array antenna 12 has a linear-to-circular polarizer 18 disposed at the output of the feed horns 12. The frequency selective surface filter 20 or 50 as explained herein rejects signals which may be produced as high frequency second and third harmonics due to the non-linear characteristics of the amplifiers 16. The frequency selective surface filter 50 of the present invention rejects signals with certain frequencies so it will not interfere with other antenna operations.

Referring to Figure 2, the frequency selective surface filter 20 is shown in a cross-sectional view containing a single conductive screen. The single conductive screen is hereafter referred to as the single-screen frequency selective surface filter 20. The single-screen frequency selective surface filter 20 contains a single conductive circuit layer 24 made up of a conductor printed or otherwise fabricated on top of a thin planar dielectric layer 22. The conductive pattern provided on the single conductive circuit layer 24 may be printed or etched on the dielectric layer 22 in accordance with well known printed circuit manufacturing techniques. The thin dielectric layer 22 may include a dielectric substrate such as a known thin space qualified material such as polyamide or other suitable material. One

known dielectric is identified as Kapton which is manufactured by E.I. duPont

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de Nemours and Company, Inc.

The single conductive screen 24 is made up of a conductive material such as copper or other suitable material and is configured as shown in Figure 3. The frequency selective surface filter 20 includes a gridded square array made up of a first plurality of parallel conductive lines 26 perpendicularly intersecting a second plurality of parallel conductive lines 28. The gridded square array therefore provides for a plurality of square regions separated by the perpendicularly intersecting parallel conductive lines 26 and 28. The width of the conductive lines 26 and 28 is represented by W_1. The distance between adjacent parallel conductive lines 26 and also between adjacent parallel conductive lines 28 is represented by P. The distance P represents the periodic interval of the square regions provided by conductive lines 26 and 28. In effect, the gridded square array made up of conductive lines 26 and 28 provides a low frequency rejection band which advantageously filters out low frequency signals.

The multibeam phased array antenna 10 further includes an array of double-loop conductive elements provided in the square regions. Each of the double-loop conductive elements is made up of an inner-conductive loop 32 configured within an outer conductive loop 30. The inner conductive square loop 32 has a width identified as W_3, while the outer conductive square loop 30 has a width identified as W_2. The frequency rejection bandwidth may be realized as a function of the widths W_2 and W_3. Accordingly, widths W_2 and W_3 are related with a widened size to provide a widened band of rejection. The inner and outer

conductive square loops 30 and 32 are separated by a non-conductive isolation loop 34 which has a width identified as g_2. Accordingly, the outer conductive square loop 30 is dielectrically separated from the inner conductive square loop 32 by a distance g_2. In addition, outer conductive square loop 30 is separated from the conductive grid lines 26 and 28 via a non-conductive region by a distance g_1.

The array of double-loop conductive elements made up of conductive loops 30 and 32 provides for a first frequency rejection band and a second frequency rejection band. The inner conductive square loop 32 is configured with an outer conductive circumference of a distance equal to or close to the wavelength of signals to be rejected by inner conductive square loop 32. Similarly, the outer conductive square loop 30 has an outer conductive circumference configured of a distance approximately equal to or close to the wavelength of signals that are to be rejected with the outer conductive loop 30. The distance of the circumference of each of the conductive loops 30 and 32 is equal to the wavelength of a frequency substantially centered in first and second rejection bands. Depending on the widths W_2 and W_3 of the conductive loops 30 and 32, respectively and the attenuation acceptance, the first and second rejection bands extend over a range of frequencies in a rejection bandwidth.

According to one example, the single-screen frequency selective surface filter 20 may include the following geometric pattern dimensions:

P = 0.1378 Inches (3.50mm)
W_1 = 0.0043 Inches(0.11mm)
W_3 = 0.0043 Inches(0.11mm)
g_2 = 0.0043 Inches (0.11mm)
W_2 = 0.0172 Inches(0.44mm)
g_1 = 0.0172 Inches (0.44mm)

As evidenced by the above example, the single-screen frequency selective surface filter 20 can be configured with small dimensions and may consume a small volume. The above example provides generic geometric dimensions suitable for achieving a signal transmission response 40 such as that provided in Figure 4 which shows signal transmission in decibels (dB) versus frequency achievable with the single-screen frequency selective surface filter 20. The single-screen frequency selective surface filter 20 essentially provides three rejection bands 44, 46 and 48, while allowing signal transmission in a desired frequency band as evidenced by the passband 42.

In effect, the intersecting parallel conductive lines 26 and 28 provide a low-frequency rejection band 44 which filters out low frequency signals, including low frequency noise induced signals. For an attenuation drop of fifteen decibels

(15 dB), the low-frequency rejection bandwidth extends from frequencies of about zero to three GHz. The outer conductive square loop 30 provides frequency rejection band 46 to reject those signals of approximately 40.4 to 45.5 GHz. The inner conductive square loop 32 provides frequency rejection band 48 to reject signals having frequencies of approximately 60.6 to 63.6 GHz. The bandwidth of each of rejection bands 44, 46 and 48 may vary depending on the preferred attenuation. Accordingly, rejection bands 44, 46 and 48 effectively filter out noise induced signals as well as high frequency second and third harmonics which may be present due to the non-linear effects, especially those associated with the amplifier circuitry. Accordingly, the multibeam phased array transmit antenna 10 may operate effectively within the designated pass band 42, while reducing or eliminating problems associated with unwanted high frequency harmonics.

According to the present invention, the frequency selective surface filter 50 includes two conductive screen layers for providing wide band frequency filtering. The double conductive screen is hereafter referred to as the double-screen frequency selective surface filter. Referring to Figure 5, the double-screen frequency selective surface filter 50, shown in a cross-sectional view, includes a dielectric medium 58 with a first conductive screen 60 printed or otherwise fabricated on the top surface of a thin dielectric medium 58. Similarly, frequency selective surface filter 50 includes a second thin dielectric medium 54 with a second conductive screen 52 printed or otherwise fabricated on the bottom surface of the second thin dielectric medium 54. In addition, frequency selective

surface filter 50 further includes a thicker dielectric separating medium 56 disposed between the first and second dielectric mediums 58 and 54 to provide isolation between the first and second conductive screens 60 and 52. The thin dielectric materials 58 and 54 may include a dielectric material of the type identified for dielectric layer 22, while dielectric isolation layer 56 may include foam or other suitable dielectric medium which is similarly transparent to electromagnetic radiation. According to one example, the thin dielectric layers 58 and 54 may each include a thickness of 25μm (one mil), while the thicker dielectric isolation layer 56 may include a thickness of 4.8mm (189 mil).

Referring to Figure 6, the bottom conductive screen 52 is shown to include an array of double-square slots each of which includes an inner non-conductive slot 64 and an outer non-conductive slot 66 both edged in conductive screen layer 52. The inner and outer slots 64 and 66 are separated via a conductive region 68. Further, the outer slots 66 are separated from adjacent outer slots by conductive lines 69. Conductive lines 69 have a width identified as g_1. The conductive region 68 separating slots 64 and 66 has a square configuration with a width identified as g_2. The outer slot 66 has a width identified as W_1, while the inner slot 64 has a width identified as W_2. The conductive lines 69 are separated by a distance P which defines the periodic interval of the array of double-square slots.

The bottom conductive screen 52 provides first and second frequency passbands as a function of the dimensions of the inner and outer slots 64 and 66.

The inner slot 64 has a circumference of a distance equal to one wavelength of the frequency defining the first passband. The outer slot 66 similarly has a circumference of a distance equal to one wavelength of the frequency defining the second passband. The first and second passbands extend over a band of frequencies. Accordingly, signals within the first and second passbands are able to resonate through the bottom conductive screen 52, while other frequency signals are rejected.

The top conductive screen 60 is configured with an array of single-square conductive loops 62 printed or otherwise fabricated on the top surface of dielectric medium 58. Each of the conductive square loops 62 has a circumference of a distance equal to one wavelength of the frequency that defines the rejection band. The rejection band provided by conductive loops 62 effectively extends over a range of frequencies. Accordingly, the single-square loop configuration rejects signals within the rejection band as a function of the dimensions of the single-square loop. The rejection band provided by the top conductive screen 60 may be selected equal to one of the first or second passbands provided by the bottom conductive screen 52 so as to achieve multiple rejection bands and allow transmission of signals within one frequency passband. According to one example, the bottom conductive screen 52 may be configured with the following dimensions:

P = 0.1496 Inches (3.80mm)
W_1 = 0.00935 Inches (0.24mm)
g_1 = 0.00935 Inches (0.24mm)
W_2 = 0.00935 Inches (0.24mm)
g_2 = 0.02805 Inches (0.71mm)

In connection with the above-identified example, the top conductive screen 60 may be configured with the following dimensions:

P = 0.0996 Inches (2.53mm)
W = 0.0062 Inches (0.16mm)
g = 0.03735 Inches (0.95mm)

According to the above-identified example of filter 50, the double-screen configuration of the frequency selective surface filter 50 may provide operational characteristics as shown by the transmission response 70 in the graph of Figure 8. The frequency selective surface filter 50 provides a frequency passband identified as 72 which defines the frequency range over which signals are allowed to radiate through frequency selective surface filter 50. The frequency selective surface filter 50 also effectively provides wide frequency rejection bands

74 and 76. In effect, the outer slot 66 of bottom conductive screen 52 allows signals with frequencies of approximately 20.2 to 21.2 GHz to radiate through bottom conductive screen 52. Similarly, the conductive loops 62 of the top conductive screen 60 allow signals with frequencies of approximately 20.2 to 21.2 GHz to radiate through top conductive screen 60. The bottom conductive screen 52 effectively rejects signals with frequencies in the rejection band 74. The top conductive screen 60 effectively rejects signals having frequencies of 60.3 to 63.6 GHz.The bottom conductive screen 52 does provide some attenuation of the V-band frequencies and the top conductive screen 60 does provide some attenuation of the Q-band frequencies. Therefore, the combination of the top and bottom conductive screens 60 and 52 effectively rejects signals within the widened rejection band 74 and signals within the widened rejection band 76, while at the same time providing little or no attenuation of the frequencies in the passband 72.

The frequency selective surface filter 20 or 50 offers multiple frequency rejection bands in a thin, lightweight and low cost package. The single-screen frequency selective surface filter 20 provides good performance with low frequency filtering in a very thin package, while the double-screen frequency selective surface filter 50 is able to achieve widened frequency rejection to improve filtering at desired frequency bandwidths. In addition, the frequency selective surface filter 20 or 50 includes equal rectilinear (x and y) line dimensions suitable for use for both vertical and horizontal polarizations, and also suitable for circular polarization. Accordingly, the frequency selective surface filter 20 or 50 is small and lightweight and advantageously suitable for use in connection with a transmit antenna.

In view of the foregoing, it can be appreciated that the present invention enables the user to achieve a compact frequency selective surface filter suitable for use in connection with a tramsmit antenna. Thus while this invention has been disclosed herein in combination with a particular example thereof, no limitation is intended thereby except as defined in the following claims.

CLAIMS

A frequency selective surface filter for providing multiple frequency rejection bands, said frequency selective surface filter comprising:

a dielectric medium that is substantially transparent to electromagnetic signal transmission and having a top surface and a bottom surface

a plurality of double-loop slots disposed in a first conductor material on one of said top and bottom surfaces of said dielectric medium, each of said double-loop slots including an inner slot encircled by an outer slot for providing a first frequency pass-band and a second frequency pass-band while rejecting signals in a first frequency rejection band; and

an array of conductive loop elements disposed on the other of said top and bottom surfaces of the dielectric layer, for providing a second frequency band.

2. The frequency selective surface filter according to claim 1, wherein said frequency selective surface filter is disposed in communication with a multibeam phased array antenna.

3. The frequency selective surface filter according to claim 1 or claim 2, wherein said frequency selective surface filter is disposed in communication with a transmit antenna, said frequency selective surface filter filtering out higher frequency harmonics produced by non-linear characteristics of circuitry components in the transmit antenna.

4. The frequency selective surface filter according to any preceding claim, wherein said dielectric medium has substantially planar top and bottom surfaces.

5. The frequency selective surface filter according to any preceding claim, wherein each of said conductive loop elements comprises a single conductive loop.

6. The frequency selective surface filter according to any preceding claim, wherein said conductive loop elements are configured as square loops.

7. The frequency selective surface filter according to any preceding claim, wherein said double-loop slots are each configured as square slots.

8. The frequency selective surface filter according to any preceding claim, wherein said dielectric medium comprises:

a first thin dielectric substrate providing the top surface; and

a second thin dielectric substrate providing the bottom surface.

9. The frequency selective surface filter according to any preceding claim, wherein said dielectric medium further comprises a dielectric isolation layer disposed between the first and second thin dielectric substrates.

10. An antenna comprising:

one or more radiating elements for radiating electromagnetic radiation;

transmit circuitry for generating signals for transmission from said one or more radiating elements; and

a frequency selective surface filter according to any preceding claim.

Amendments to the claims have been filed as follows

1. A frequency selective surface filter for providing multiple frequency rejection bands, said frequency selective surface filter comprising:

a dielectric medium that is substantially transparent to electromagnetic signal transmission and having a top surface and a bottom surface

a plurality of double-loop slots disposed in a first conductor material on one of said top and bottom surfaces of said dielectric medium, each of said double-loop slots including an inner slot encircled by an outer slot for providing a first frequency pass-band and a second frequency pass-band while rejecting signals in a first frequency rejection band; and

an array of conductive loop elements disposed on the other of said top and bottom surfaces of the dielectric layer, for providing a second frequency rejection band.

2. The frequency selective surface filter according to claim 1, wherein said frequency selective surface filter is disposed in communication with a multibeam phased array antenna.

3. The frequency selective surface filter according to claim 1 or claim 2, wherein said frequency selective surface filter is disposed in communication with a transmit antenna, said frequency selective surface filter filtering out higher frequency harmonics produced by non-linear characteristics of circuitry components in the transmit antenna.

4. The frequency selective surface filter according to any preceding claim, wherein said dielectric medium has substantially planar top and bottom surfaces.

5. The frequency selective surface filter according to any preceding claim, wherein each of said conductive loop elements comprises a single conductive loop.

6. The frequency selective surface filter according to any preceding claim, wherein said conductive loop elements are configured as square loops.

7. The frequency selective surface filter according to any preceding claim, wherein said double-loop slots are each configured as square slots.

8. The frequency selective surface filter according to any preceding claim, wherein said dielectric medium comprises:

a first thin dielectric substrate providing the top surface; and

a second thin dielectric substrate providing the bottom surface.

9. The frequency selective surface filter according to any preceding claim, wherein said dielectric medium further comprises a dielectric isolation layer disposed between the first and second thin dielectric substrates.

10. An antenna comprising:

one or more radiating elements for radiating electromagnetic radiation;

transmit circuitry for generating signals for transmission from said one or more radiating elements; and

a frequency selective surface filter according to any preceding claim.

The Patent Office

Application No: GB 9913784.6
Claims searched: all

Examiner: Dr E.P. Plummer
Date of search: 20 September 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H1Q (QEC, QEJ, QEX, QJC), H1W (WBA, WBX)

Int Cl (Ed.6): H01P, H01Q, H03H

Other: Online: JAPIO, WPI, CLAIMS, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
AE	GB2328319A British Aerospace eg figure 2	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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